The role of strategy selection, limb force capacity and limb positioning in successful trip recovery

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Abstract

Background Fall occurrence, mainly due to tripping, increases with age. There are two main strategies of trip recovery: elevating and lowering. Strategy selection depends on trip stimulus timing within the swing phase of walking, but the choice and ultimate success of a strategy selection may also depend on individual physical characteristics.

The aim of this study was to investigate: 1) recovery strategy choice by younger and older adults when perturbed in the 'strategy overlap' mid-swing phase, and 2) whether the interaction between recovery limb positioning and recovery limb force capacity determines recovery success in elevating strategy recoveries and accounts for strategy selection.

Methods A group of older (65-75 years) and a group of younger adults (20-35 years) completed a trip recovery protocol in a laboratory environment.

An inverted pendulum model was developed to investigate how walking speed, recovery limb positioning and recovery limb force interacted and influenced successful trip recovery when perturbed in different swing phases.

Findings Older adults always adopted a lowering strategy when perturbed in late mid-swing (60-80%), while younger adults also adopted elevating strategies. Simulations showed that, when perturbed later in swing, a larger recovery step and higher recovery limb force were required for successful recovery.

Interpretation We suggested that a combination of insufficient recovery limb strength, response time and movement speed make it difficult for older adults to achieve a large enough recovery step for a successful elevating strategy recovery when perturbed later in mid-swing.

Keywords

Balance; walking; lower limb; elderly; fall prevention

1. Introduction

Approximately one in three people aged over 65 fall at least once a year, mainly due to tripping (Tinetti et al. 1988). Most studies investigating biomechanical aspects of trip recovery have focussed on response time (Bogert van den et al. 2002; Ferber et al. 2002; Hsiao and Robinovitch 1999; Smeesters et al. 2001), lower limb strength (Pavol et al. 2002; Pijnappels et al. 2008; Wojcik et al. 2001) and muscle activation (Burg van der et al. 2007; Pijnappels et al. 2005).

In early trip recovery (prior to recovery limb ground contact) the body's forward angular momentum will be reduced by the initial stance limb (Pijnappels et al. 2005), arm movement (Roos et al. 2008) and trunk stiffness (Burg van der et al. 2005), while in late trip recovery (during recovery limb ground contact) it is mainly reduced by the actions of the recovery limb and trunk stiffness. Pijnappels et al. (2005) demonstrated that younger adults were generally more capable than older adults to restrain the body's forward angular momentum using the initial support (trailing) limb prior to recovery limb contact. It is however unknown how recovery limb strength and positioning interact to influence recovery success.

The role of the recovery limb may depend on age and on the recovery strategy ('elevating' or 'lowering') employed (Eng et al. 1994). In an elevating strategy the obstructed limb is lifted over the obstacle and in a lowering strategy the obstructed limb is placed prior to the obstacle and the contralateral limb is lifted over the obstacle (Eng et al. 1994). Strategy selection depends on the timing of the trip stimulus within the swing phase of the walk (Schillings et al. 2000). Early swing perturbations result in elevating strategy recoveries (Schillings et al. 2000) as the centre of mass (CM) is posterior to the centre of pressure (CP), leaving time to lift the obstructed limb over the obstacle. Late swing perturbations result in lowering strategy recoveries (Schillings et al. 2000) as the CM is already anterior to the CP and the swing foot is close to the ground; it is therefore easiest to immediately lower this foot to the ground and recover in subsequent steps. Around mid-swing there will be a ‘strategy overlap’ phase where strategy selection is mechanically not obvious.

Older adults more often adopt a lowering strategy recovery than younger adults (Pavol et al. 2001; Pijnappels et al. 2005), but it is not understood why. It could be that they are incapable of or unwilling to use an elevating strategy later in swing when this strategy may become more demanding.

Therefore, the aim of this study was to investigate: 1) the recovery strategies used by younger and older adults when perturbed in the ‘strategy overlap’ mid-swing phase and the success of these; and 2) whether the interaction between recovery limb positioning and recovery limb force capacity determines recovery success in elevating strategy recoveries and accounts for selection of strategy. Aim 1 was investigated using an experimental approach, while aim 2 was investigated using a simple modelling approach. The angular motion resulting from a trip can be simplified and modelled as pendular movement. Van den Bogert et al. (2002) demonstrated, with an inverted pendulum model, that reduced response time was more important for successful trip recovery than lower walking speed. Another inverted pendulum model, by Hsiao and Robinovitch (1999), showed that an interaction between step length, leg strength and step contact time determined the range of possible perturbations that could be recovered from in static lean-release experiments.

We hypothesised that the shift to using lowering instead of elevating strategy recoveries occurs earlier for older than for younger adults. Our second hypothesis was that recovery limb positioning at ground contact influences the muscle force required for successful trip recovery and that appropriate recovery limb positioning becomes essential in situations close to the limits of successful recovery. Our final hypothesis was that a higher recovery limb force capacity (defined as the maximum force which can be developed in the limb) allows for recovery in more challenging trip situations, such as in response to later perturbations, larger perturbations and with non-optimal recovery limb placement.

2. Methods

2.1 Trip recovery experiment

Protocol The experimental methods were similar to those described previously (Roos et al. 2008). Briefly, following sample size calculations to allow detection of significant differences in kinematic measures (e.g. step length), female participants were recruited from the local community into a ‘younger’ group aged 20 to 35 years (n=8) and an ‘older’ group aged 65 to 75 years (n=7) via poster advertisements and personal contacts. To exclude gender effects only female participants were used. The local NHS (National Health Service UK) research ethics committee approved the experimental procedures (04/Q2001/169 and 05/Q2001/214) and written informed consent was obtained from all participants. Characteristics for the participants are described in Table 1. All participants were recreationally active and healthy, with no BMI (Body Mass Index) above 28, no use of medication that may cause dizziness, no history of repetitive falling and no fear of falling (assessed via the SAFFE questionnaire (Lachman et al. 1998)). Trips were induced in random walking trials, by a custom-built device, at varying time points of the swing phase. The participants were secured in a safety harness to prevent impact with the ground. Kinematic data were collected with a CODA CX1 system

(Charnwood Dynamics Ltd., United Kingdom) at 200 Hz.

Data analysis Kinematic data were processed as described in (Roos et al. 2008). The percentage of the swing phase at which trips were induced ($\%_{swing}$) was expressed in relation to the average swing duration of all walking trials. $\%_{swing}$ was calculated by dividing the swing time prior to the perturbation by this average swing duration.

To investigate recovery limb positioning, the recovery step length (RSL) was calculated. This was calculated as the anterior-posterior distance between the ankle coordinates of the obstructed foot at contact with the tripping device and the ankle coordinates of the recovery leg at contact with the force plate, expressed normalised to leg length.

Peak horizontal and vertical ground reaction forces (GRF) during ground contact of the recovery limb were calculated to give an indication of the maximum force in the recovery limb.

For statistical analyses, differences between groups were assessed using independent t-tests and relationships between mechanical variables were assessed with Pearson product-moment correlations. Statistical significance was accepted at the $P \leq 0.05$ level.

2.2 Trip recovery inverted pendulum simulation model

Model structure To understand how recovery limb positioning and force capacity influence trip recovery success, a two-dimensional simulation model was developed and its outcomes were compared with experimental results. An inverted pendulum model with similarities to the model by Hsiao and Robinovitch (1999) was used, but it differed from the previous model in that it simulated trip recovery, not balance recovery from static lean-release, and thus it had an initial walking velocity.

The trip recovery model was developed in Simmechanics (Matlab 2007a, The Mathworks). It consisted of a rigid segment (representing the upper body and initial stance limb) with a body mass (m_{body}) and height (h_{body}). The body CM was placed halfway along the length of the rigid segment. A rotational spring (stiffness K_{rot}) at the base of this segment simulated the reduction of the body's forward angular momentum by the initial stance limb. A massless segment with a linear spring (stiffness K_{lin}) was attached to the body segment with a fixed hinge joint (hip) at leg length height (Figure 1). This spring simulated the reduction of the body's forward angular momentum by the recovery limb during the first recovery step. A larger K_{lin} stiffness represented a larger recovery limb force capacity (i.e. capable of generating a large force in the recovery limb). Body positioning was defined by the body inclination angle (θ) and the angle of the swing limb relative to the body (α) (Figure 1).

The impulse from the trip force was ignored as it was relatively small in the trip recovery experiments (it did not exceed 43 N). Based on the assumptions of inverted pendulum motion, it was assumed that at a trip the linear momentum of walking would be directly translated into angular momentum. The initial angular velocity of the body CM (ω_0) was therefore directly calculated from the walking speed (v_{walk}):

Equation 1 $$\omega_0 = \frac{360 * v_{walk}}{\pi * h_{body}}$$

The model consisted of a pre-contact and a contact phase sub-routine. The pre-contact routine (which simulated the action of the initial stance limb) ended when the recovery limb contacted the ground or if successful recovery was achieved through the initial stance limb alone. The contact sub-routine was initiated with the end-points of the pre-contact routine. The stop conditions for the contact routine were if either successful recovery or a fall occurred. Successful recovery was achieved when the angular momentum was reversed (ω<0°/s) and a fall occurred when θ>90°. The exact critical θ value for when a fall would occur did not need to be defined as when this angle was exceeded the body would continue to fall and rotate forward to eventually exceed 90°.

The natural length of the linear spring ($Lleg_{contact}$) was assumed to be shorter than the leg length since the recovery limb is not fully extended at ground contact. It was set to 0.98 times the leg length (agreeing with the average knee angle at recovery limb contact for elevating strategy experimental trials: 159°±11°).

Outcome variables were values indicating whether successful recovery was possible and the maximum force at the linear spring during the contact phase (F_{max}). F_{max} was calculated by multiplying the recovery limb displacement by its stiffness K_{lin} and storing its maximum value.

Parameter estimation The parameters K_{lin} and K_{rot} were estimated with the 'response optimization' toolbox of Simulink. K_{rot} was estimated within the pre-contact routine and K_{lin} within the contact routine, both matching experimental data for θ and ω as closely as possible. The experimental body inclination angle was calculated, throughout trials, as the angle of the line through the ankle and CM with a line perpendicular to the ground. These experimental data were obtained from elevating strategy trials without a flight phase for which a full body marker data set was available (five trials in total).

Simulations A Matlab routine linking the sub-routines was used to run multiple simulations varying $\%_{swing}$ and v_{walk}. The dimensions of the inverted pendulum model were h_{body} = 1.70 m, m_{body} = 61.0 kg, leg length = 0.88 m. These were average values of the subjects whose trials were used in the parameter estimation. The average estimated value for K_{rot} was used (1850 Nm/rad). K_{lin} was varied between 5000 N/m and 25000 N/m, as estimated values from experimental data were between 4966 N/m and 30559 N/m. To represent trips from early to late swing, $\%_{swing}$ was varied between 30% (where θ_0 = -8°) and 90% (where θ_0 = 16°). α was varied between 0 and 90°. v_{walk} was varied between 0.25 and 1.5 m/s. The range of initial values for α and v_{walk} were larger than those of the experimental values to achieve a wider range of trip perturbation and recovery scenarios in the simulations.

Sensitivity analysis A sensitivity analysis was conducted to investigate whether the maximum force (F_{max}) required to recover successfully was more sensitive to variations in α or to variations in v_{walk}. α and v_{walk} were varied one standard deviation (9° and 0.2 m/s) from a mid-range value (α = 35° and v_{walk} = 0.75 m/s) and their F_{max} values were compared to that for the mid-range value. α was increased by one standard deviation from the mid-range value as this would increase the moment arm to reverse the body angular momentum and therefore reduce the required recovery effort. v_{walk} was decreased by one standard deviation from the mid-range value as a slower walking speed would result in a smaller body angular momentum after the trip perturbation and would therefore also reduce the required recovery effort.

3. Results

3.1 Experimental results

The percentage of swing at which the trip perturbation occurred ($\%_{swing}$) was calculated for 61 trip trials for the younger adults (with 59% elevating strategies) and for 89 trials for the older adults (with 20% elevating strategies). Perturbations occurred at random percentages of swing and the average percentage of swing at which trips occurred was not significantly different between younger and older adults (57% (SD 19%) and 71% (SD 23%) respectively) although a tendency for older adults to receive perturbations later in the swing phase was observed.

Both younger and older adults always used an elevating strategy when perturbed in early swing (<40%), always a lowering strategy when perturbed in late swing (>80%), and elevating as well as lowering strategies when perturbed in early mid-swing (40-60%) (Figure 2). Responses to perturbations in late mid-swing (60-80%) differed between younger and older adults; older adults always adopted a lowering strategy, while younger adults also adopted elevating strategies (Figure 2).

Trials in which a fall occurred (>30% of body weight supported by the safety harness, n = 11, 4 from older group, 7 from younger group) were analysed purely to describe the $\%_{swing}$ of the perturbation. None of the falls occurred in response to early swing perturbations, one in response to an early mid-swing perturbation, seven in response to late mid-swing perturbations and three in response to late swing perturbations.

Older adults showed a significantly ($p<0.01$) smaller recovery step length (RSL) than younger adults during elevating strategies (0.61 and 0.81 LL respectively, table 2). Younger adults showed a positive correlation ($r = 0.727$, $p<0.001$) between RSL and $\%_{swing}$ during elevating strategy recoveries, meaning they took larger recovery steps when perturbed later in swing. This correlation was not present in the older adults ($r = 0.040$, $p = 0.887$). Maximum horizontal and vertical GRF were not correlated with walking speed or RSL for elevating strategy recoveries of younger and older adults.

3.2 Simulation results

Simulation results for variations in α and v_{walk} are shown in surface plots (Figure 3). An increased v_{walk} resulted in unsuccessful recovery for small α values. For the medium α

values, where successful recovery was possible, an increased v_{walk} resulted in an increased F_{max} required for successful recovery. For large α values, successful recovery was possible before the recovery limb contacted the ground (F_{max} = 0 N). As the recovery limb was placed more forward there was more time available in the pre-contact phase to reduce the forward angular momentum of the body. An increased recovery limb force capacity (K_{lin}) allowed successful recoveries for progressively smaller α values.

When perturbed later in swing a higher F_{max} was required to recover successfully. Perturbations in mid-swing (50%) resulted in successful recoveries for small α values combined with small v_{walk} values, while later in swing (70% and 90%) these resulted in unsuccessful recoveries. When a perturbation occurred at 70% of swing, the maximum force required to recover successfully (F_{max}) was more sensitive to an increase of the recovery step length (α) than to a decrease of the walking speed (v_{walk}) for all recovery limb force capacity values (K_{lin}) (Table 3). Later in swing ($\%_{swing}$ = 90%) F_{max} was also more sensitive to an increase of recovery step length (α) than to a decrease of the walking speed (v_{walk}) for a recovery limb force capacity value (K_{lin}) of 5000 N/m. However for the higher recovery limb force capacity values (K_{lin} = 15000 and 25000 N/m) F_{max} was more sensitive to a decrease in walking speed (v_{walk}) than to an increase in recovery step length (α).

4. Discussion

This study sought to determine whether trip recovery strategy selection differed between younger and older adults, particularly in the mid-swing phase, and to establish the interaction between recovery limb positioning and recovery limb force capacity in determining recovery success. We found that older adults made the transition to lowering strategies earlier in the swing phase, and that recovery success following late swing perturbations was influenced by the ability to position the recovery limb and the maximum force capability of the limb.

Older participants less often adopted an elevating strategy than younger participants (20% vs. 59% of trials), in agreement with previous studies (Pavol et al. 2001; Pijnappels et al. 2005), which may have been partly due to the fact that the older adults received more trips later in swing (Figure 2) and had a slightly reduced walking speed prior to trip (1.11 LL/s for older adults versus 1.22 LL/s for younger adults). However, irrespective of differences in walking speed which should make both types of recovery strategy easier due to less forward angular momentum, our findings show that different strategies were employed in late mid-swing (60-80%), where younger adults adopted either an elevating or a lowering strategy, while older adults adopted a lowering strategy recovery only (except for one instance) (Figure 2). This confirms our first hypothesis that the shift from adopting a lowering strategy instead of an elevating strategy recovery is made earlier for older (%swing ≈ 60%) than for younger adults (%swing ≈ 80%). We also found that most falls occurred in responses to perturbations in late-mid or late swing, although the number of falls induced was too few to confirm this speculation. Our experiments were designed to cause tripping and not falling, so we can therefore only show a possible tendency for more falls to occur when perturbed later in swing, and future research will have to show whether this tendency is significant. Nevertheless, based on these findings, we suggest the late mid-swing phase to be a more challenging phase for older adults, as they did not use an elevating strategy recovery in this phase, which we propose to be a more effective strategy for full recovery in initial steps following a perturbation.

The proposition that an elevating strategy would be more effective but more difficult than a lowering strategy recovery when individuals are perturbed later in swing is based largely on the tenet that for an elevating strategy: (1) there is more time available to counteract the forward angular momentum by the initial stance limb, as described by (Pijnappels et al. 2004), and (2) the recovery limb is lifted over the obstacle and placed more anterior relative to the body CM, providing a larger moment arm to reduce the body's forward angular momentum (Pijnappels et al. 2004). It will however become more difficult to elevate the swing limb over the obstacle when perturbed later in swing, as the body CM moves more anterior relative to the CP. Our simulations confirmed that an elevating strategy recovery becomes more difficult later in swing, as larger forces were required in the recovery limb and successful recovery was not always possible with smaller recovery steps. The experimental data of the younger adults also showed a larger recovery step size when perturbed later in swing, as RSL was positively correlated with $\%_{swing}$; this relationship was not evident in the older adults group. When perturbed later in swing, the swing leg is already placed more forward relative to the CM, there is however less time available for optimal recovery limb placement. A larger step would provide a larger moment arm to reduce the angular momentum due to a trip. We therefore expect that the larger recovery steps younger adults took when perturbed later in swing would be beneficial to them to continue using an elevating strategy but would require increased movement speed.

During elevating strategy recoveries, older adults took smaller recovery steps (mean RSL = 0.61 LL) than younger adults (mean RSL = 0.81 LL). The simulations showed that a smaller α (corresponding to a smaller recovery step) required a larger F_{max} to successfully recover from a trip, and successful recovery was not possible for the very small α values (Figure 3). This supports our suggestion that a larger recovery step later in swing by younger adults is beneficial to them to continue using an elevating strategy when perturbed later in swing, as larger recovery steps require a smaller F_{max}. This suggests that it is a combination of recovery limb force capacity and recovery limb placement (influenced by reduction of the body forward angular momentum by the initial stance limb, response time and recovery limb movement velocity) that limit successful recovery in older adults. It confirms the second hypothesis that recovery limb positioning influences the force required to recover from a trip and that appropriate recovery limb positioning is essential for successful recovery in situations close to the limits of recovery. This agrees with simulations by Hsiao and Robinovitch (1999) which showed recovery success from lean-release to be dependent on a coupling between step length, step execution time and leg strength.

To confirm the third hypothesis, the simulation results showed that a larger recovery limb force capacity (K_{lin}) allowed successful recovery in more challenging situations, in response to later perturbations, larger perturbations (increased walking speed) and recoveries using smaller α values (Figure 3). Within the model, for perturbations in late mid-swing with a recovery limb force capacity (K_{lin}) of 5000 N/m, the maximum force in the recovery limb required to recover successfully from a trip (F_{max}) was more sensitive to variations in recovery step length (α) than to variations in walking speed (v_{walk}) (Figure 3 and Table 3). As recovery step length is influenced by response time, these results agree with findings by van den Bogert et al. (2002) that response time was more important for successful lowering strategy recoveries than walking speed. However, we found that for perturbations in late mid-swing in simulations with higher force capacity (K_{lin} =15000 and 25000 N/m), the maximum force in the recovery limb required to recover successfully from a trip (F_{max}) was not as sensitive to variations in recovery step length (α) and became more sensitive to variations in v_{walk} (Figure 3 and Table 3). Recovery success is often limited in older adults, as they generally have a smaller recovery limb force capacity (and therefore cannot generate as high values of F_{max}) and a reduced recovery limb movement speed (and therefore cannot achieve the highest α values). Our simulations imply that older adults would benefit most from a faster response time and increased limb movement speed in order to achieve a sufficiently large recovery step length. When perturbed later in swing, an increased step length does not substantially improve recovery success of elevating strategy recoveries and lowering strategy recoveries would be more beneficial. On the other hand, younger adults who are inherently stronger may be more influenced by walking speed than response time with regards to their trip recovery success.

The experimental data of the younger adults agreed better with the simulation outcomes than those of the older adults. This was mainly due to the fact that the experimental parameters of the older adults showed no correlation with $\%_{swing}$, which was most likely due to older adults not adopting elevating strategy recoveries in response to perturbations in late mid-swing. Also the range of recovery step length (younger: 0.48 to 1.12 LL versus older: 0.42 to 0.80 LL) and maximum vertical GRF (younger: 947 to 2326 N versus older: 768 to 1422 N) was greater in younger than in older adults. This supports the suggestion that older adults were limited in recovery limb force and movement speed and response time to create a larger recovery step and could therefore not adopt an elevating strategy recovery when perturbed later in swing.

When interpreting the simulation modelling outcomes it has to be kept in mind that the model is a simplification of reality. The simulations predict only trends of trip recovery behaviour. The benefit of using a simulation modelling approach was that it allowed investigating a wide range of trip perturbations and recovery scenarios. To investigate specific physical requirements for successful trip recovery on an individual basis a more sophisticated simulation model of trip recovery would be required, and this is part of our ongoing work.

5. Conclusions

Older adults were unable or unwilling to use an elevating strategy when perturbed during late mid-swing (60-80%), while younger adults adopted either an elevating or a lowering strategy. Simulations with an inverted pendulum model, supported by experimental data, showed that a combination of recovery limb positioning and recovery limb strength limited the use of an elevating strategy in this late mid-swing phase in older adults. We suggested this phase may be more challenging for older adults than for younger adults. Some studies have shown that slip and trip recovery responses may be improved by training (Bieryla et al. 2007; Pavol et al. 2004). The results of this study suggest that trip training should focus on both speed and strength aspects and practice responses to perturbations in this challenging late mid-swing phase.

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Captions to illustrations

figure 1

Structure of the inverted pendulum trip recovery model, with θ the body angle relative to the vertical, α the angle of the recovery limb relative to the body, K_{rot} the rotational spring stiffness, and K_{lin} the linear spring stiffness.

figure 2

The use of elevating and lowering strategy recoveries by younger (Y) and older (O) adults in response to perturbations in certain phases of swing of a walk ($\%_{swing}$).

figure 3

F_{max} surface plots from simulations with the trip recovery pendulum model, with the recovery limb angle (α) on the horizontal axis, v_{walk} on the vertical axis and F_{max} on the surface. White areas on the surface plots indicate where trip recovery was unsuccessful (a fall resulted). F_{max} was 0 N when successful recovery was achieved within the pre-contact sub-routine prior to recovery limb ground contact. K_{lin} increases from the top to the bottom row, where figures a-c are for a K_{lin} of 5000 N/m, figures d-f for a K_{lin} of 15000 N/m and figures g-i for a K_{lin} of 25000 N/m. The time of perturbation ($\%_{swing}$) increases from the left to the right column, where figures a, d and g represent perturbations at 30% of swing, b, e and h represent perturbations at 70% of swing and c, f and i represent perturbations at 90% of swing. The red crosses are at α=35° and v_{walk}=0.75 m/s with red arrows indicating an increased α by one standard deviation (A, C, E, G, K and M) and a decreased v_{walk} by one standard deviation (B, D, F, H, L and N).

Table 1

Characteristics of the younger and the older participant group with mean values and standard deviations.

	Age (years)	Body mass (kg)	Height (m)	Lower limb length (m)
Younger	26.1 (3.5)	63.2 (8.4)	1.67 (0.04)	0.89 (8.4)
Older	70.0 (2.5)	64.2 (4.8)	1.66 (0.06)	0.87 (0.02)

Table 2

Mean recovery step lengths (RSL) for elevating and lowering strategies of younger and older adults with standard deviations. Significant differences to younger subjects (p<0.001) are indicated with *. No significant differences were found in RSL between elevating and lowering strategies.

		RSL (LL)
Younger	Elevating	0.81 (0.23)
	Lowering	0.82 (0.24)
Older	Elevating	0.61 (0.11)*
	Lowering	0.67 (0.27)*

Table 3

The sensitivity of F_{max} (the maximum force in the recovery limb required to recover successfully from a trip) to changes in α and v_{walk}. F_{max} was 0 N when successful recovery was achieved before the recovery limb contacted the ground. The letters and numbers in brackets after the F_{max} values correspond to the letters and numbers of the data points in figure 3.

		F_{max} (N)		
$\%_{swing}$	K_{lin} (N/m)	mid-range value	α + 9°	v_{walk} -0.2 m/s
70%	5000	1234 (1)	0 (A)	1176 (B)
	15000	1260 (2)	0 (C)	1141 (D)
	25000	1413 (3)	0 (E)	1253 (F)
90%	5000	1393 (4)	1235 (G)	1345 (H)
	15000	1554 (5)	1531 (I)	1469 (J)
	25000	1799 (6)	1802 (K)	1688 (L)

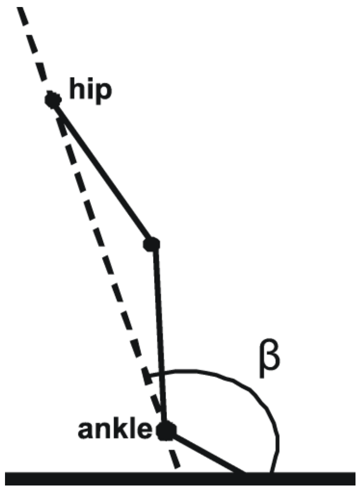

Figure 1

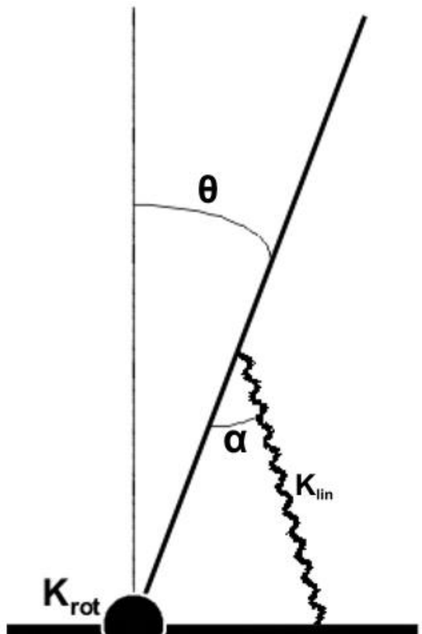

Figure 2

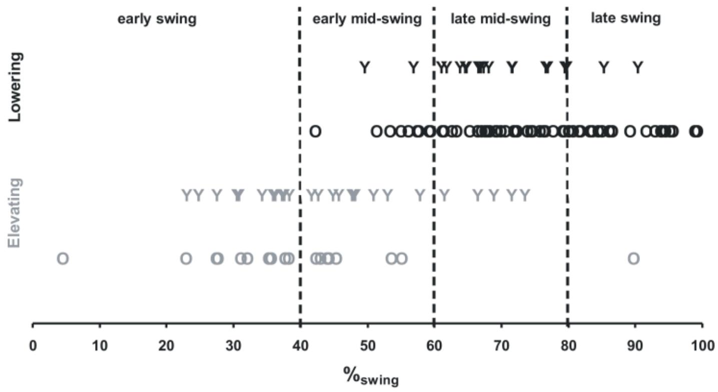

Figure 3

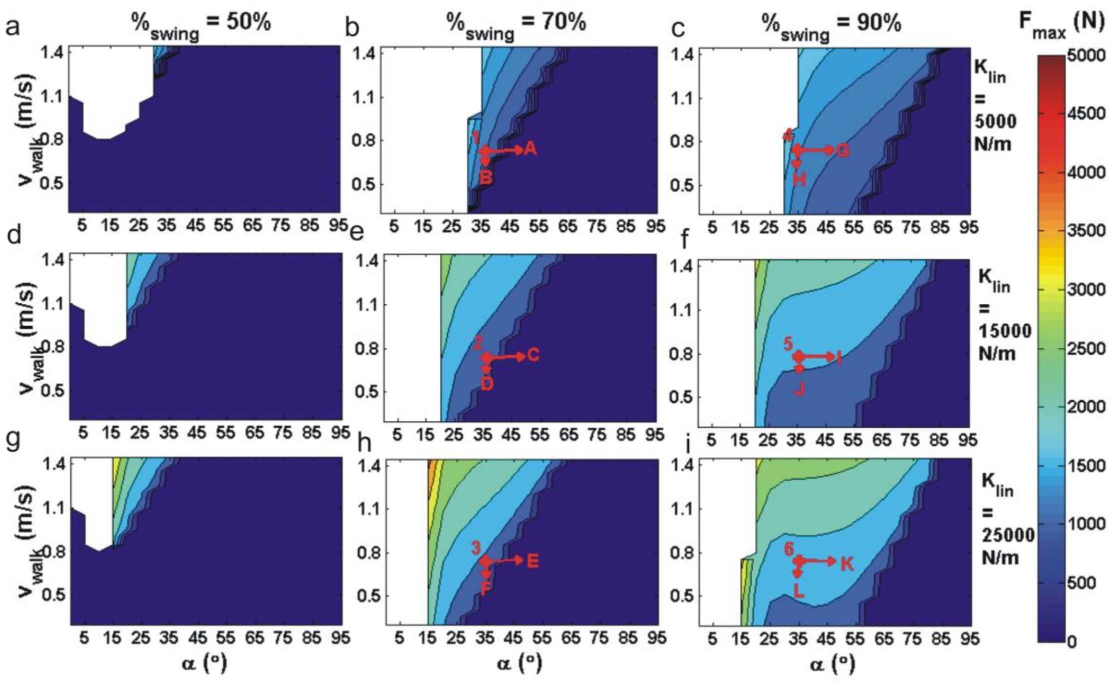

Figure 4